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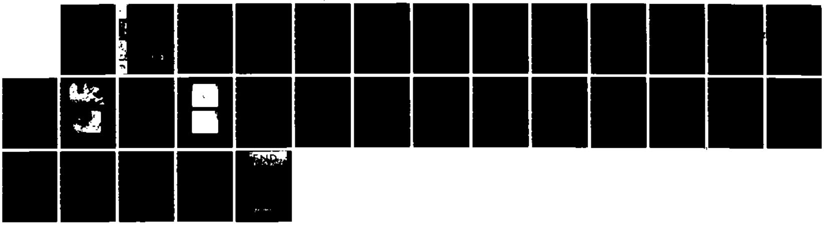

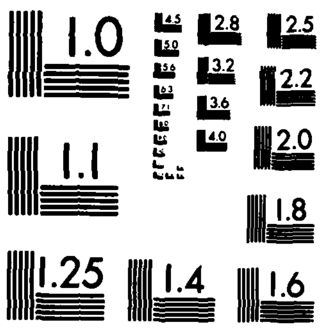
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Army Corps Engineers

AD-A146 888

TECHNICAL REPORT SL-84-12

REACTIVITY OF QUARTZ AT NORMAL TEMPERATURES

by

Alan D. Buck, Katharine Mather

Structures Laboratory

DEPARTMENT OF THE ARMY
Waterways Experiment Station, Corps of Engineers
PO Box 631
Vicksburg, Mississippi 39180

July 1984

Final Report

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This project involved a study of eight natural gravels composed largely of quartz and quartzite. It was shown that strained quartz can be a potentially deleteriously reactive constituent of concrete aggregate, and criteria were developed to recognize such material before its use as concrete aggregate. An aggregate should be regarded as potentially deleteriously reactive if it contains more than 20 percent strained quartz having an average undulatory extinction angle larger than 15 deg. Such an aggregate should then be tested

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20 ABSTRACT (Continued).

in mortar bars stored at 60°C. If the aggregate is a fine aggregate, it should be used as the aggregate in making the mortar. If the aggregate is a coarse aggregate, five particles of suitable size should be embedded in the mortar bar. An expansion of 0.025 percent in 6 months or 0.040 percent in 12 months is confirmation of its potential reactivity and the need for control measures. These criteria were incorporated into Appendix B, "Alkali-Silica Aggregate Reactions," of the Corps of Engineers Standard Practice for Concrete for Civil Works (EM 1110-2-2000) by a change dated 25 March 1983.

Preface

This project involved the study of the reactivity of quartz. It was authorized in 1974 and started in 1975 as In-House Laboratory Independent Research (ILIR) Project No. 4A061101A91D. Katharine Mather was Project Leader. All of the laboratory work was done in the Structures Laboratory (SL) of the U. S. Army Engineer Waterways Experiment Station (WES). The work was under the supervision of John M. Scanlon, Chief, Concrete Technology Division, and Bryant Mather, Chief, SL. The report was prepared by A. D. Buck. Others actively engaged in the work included J. P. Burkes, G. S. Wong, Jay E. Rhoderick, Ron Reinhold, J. F. Jones, and T. G. Ray.

Commander and Director of the WES during preparation and issuance of this report was COL Tilford C. Creel, CE. F. R. Brown was Technical Director.

Contents

Conversion Factors, Non-SI to SI (Metric)

Units of Measurement

Multiply	by	To Obtain
inches	25.4	millimetres
angstroms	0.1	nanometres
pounds (force) per square inch (psi)	6.894757	kilopascals
Fahrenheit degrees	5/9	Celsius degrees or Kelvins*

* To obtain Celsius (C) temperature readings from Fahrenheit (F) readings, use the following formula: $C = (5/9)(F - 32)$. To obtain Kelvins (K) readings, use: $K = (5/9)(F - 32) + 273.15$.

REACTIVITY OF QUARTZ AT NORMAL TEMPERATURES

Introduction

1. The reaction between alkalies in portland cement and minerals, mineraloids, and rocks containing reactive minerals and mineraloids has been effectively controlled in the U. S. by specifying cement containing less than 0.60 percent total alkali expressed as Na_2O (percent Na_2O + 0.658 × percent K_2O). This course is becoming more difficult, as new cement plants contain kilns designed to conserve energy which also have the effect of retaining more of the alkalies in the finished product. Pollution controls which reduce stack emissions also cause increased return of alkalies from stack dust to finished cement. Therefore, the Corps of Engineers and other construction agencies must seek other means of identifying the reactive aggregate and controlling the reaction. Although several practical courses such as increased use of pozzolan are available, certain basic information about the alkali-silica reaction was still missing as of 1974. One such missing piece of important basic information was a reasonable explanation of the circumstances that in at least two documented cases have caused coarsely grained quartzite and vein quartz to react with alkalies in cement and produce significant distress. The explanation of reactive quartz is a necessary first step toward the answer to another question called to our attention in 1973: the alkali-silica reactivity of certain granite gneisses and of certain metamorphic subgraywackes containing quartz, several feldspars, two micas, and accessory minerals also needed explanation. Gillott et al (1973) and Mehta (1974) support a hypothesis of the reactivity and expansion of micas but the questions about granite gneiss and metamorphic subgraywackes must also include a determination of the behavior of the quartz. In the granite gneisses, evidence of reactivity of the quartz is strong. Fundamental information is needed as a basis for improved methods for discrimination in the use of aggregates in portland-cement concrete.

2. It should be possible to reproduce in the laboratory alkali-silica reaction like that documented in "Concrete Cores from Dry Dock No. 2, Charleston Naval Shipyard, S. C." (Buck and Mather 1969). The alkali content of the cement was unknown. The coarse aggregate was gravel composed of quartzite and perhaps vein quartz; the fine aggregate was quartz, quartzite, and feldspar.

It should also be possible to reproduce similar circumstances illustrated by Brown (1955) in his figures 5, 15, and 16, and those figured and discussed in Math·r (1973).

3. Since low-quartz in coarse grain sizes has not been included in the forms of silica known to be alkali-silica reactive at normal temperatures, but is well known to be reactive at elevated temperatures (175^{o} C), this project should be conducted within a temperature range between 0^{o} C and the highest temperature likely to have occurred in building the gravity-section wall of the Charleston Dry Dock No. 2, presumably less than 69^{o} C, a maximum heat-rise figure in concrete reported by Lea (1970), (38 to 45^{o} C in concrete cured adiabatically is more usual), without allowing maintenance of the elevated temperature longer than would happen in a structure.

4. Whether or not the phenomena are reproduced exactly, and it may not be possible to do so since the aggregates in the concrete in the Charleston Naval Dry Dock (Buck and Mather 1969) and in the bridges (Mather 1973) have been repeatedly subjected to tests for alkali-silica reactivity without developing evidence of it in the laboratory although it is clear in aged concrete, it should still be possible to produce one or more working hypotheses subject to laboratory verification defining the special environmental conditions, or the special features of reactive quartz that make it reactive. These may include high concentrations of dislocations or microfractures or strains caused by deformation in the crystals, adsorbed or included ions of unusual type, unusual surface properties, defects and holes, or a mixture of some of these with other effects.

Scope of work

5. The following silica minerals or mineraloids or rocks are known to be alkali-silica reactive:

a. Rocks. Chert, known as flint in the United Kingdom.

b. Mineraloids.

(1) The several forms of common opal and presumably precious opal.

(2) Vitreous silica.

c. Minerals or varieties.

(1) Tridymite.

(2) Cristobalite.

(3) Interlayered disordered cristobalite or cristobalite tridymite (one kind of common opal).

(4) Chalcedony (microcrystalline fibrous silica).

Siliceous natural and manufactured glasses are also reactive. Thus, the scope of work includes:

a. Extending the literature study which has been in process at a low level on peculiar quartz.

b. Accumulating samples of quartz gravel, quartz crystals, amethyst, rock crystal, and unstrained quartzite.

c. Characterizing these by use of all the available instruments.

d. Measuring the extent of stress by the effects of the low to high quartz inversion at 573^{o} C or the quartz-cristobalite conversion at 1200^{o} C.

e. Causing radiation damage if possible to determine its effect on production of alkali-silica reactivity.

f. Investigating of etching effects as possible means of differentiating reactive from nonreactive.

g. Deforming some undeformed cores of quartzite such as the Sioux orthoquartzite triaxially with 200-ksi confining pressure and 1.5 $\times 10^{6}$-psi axial pressure and see if that would develop damage adequate to produce an alkali-silica reactive material.

h. Testing the treated and untreated quartz samples with high-alkali cement as concrete and mortar specimens in various conditions expected to produce reactivity in the quartz, including relative humidity over 95 and thermal cycles such as the Charleston Naval Dry Dock may have seen. It may be preferable to cycle humidity and temperature.

i. In conjunction with Purdue University, use their high-pressure mortar squeezer to expel and analyze liquid from mortar specimens of high-alkali cement and coastal plain gravel crushed to sand sizes.

Materials and Procedures

6. The work actually conducted consisted of the characterization of 8 siliceous gravels, testing of 14 or 15 selected pebble* halves, and long-term length-change testing of mortar bars containing 5 or 10 embedded quartz or

* The term "pebble" is used in this report to refer to particles larger than 12.5 mm but smaller than 19.0 mm taken from natural water-worn gravel and hence rounded in shape. Nothing is meant to be implied from such usage about limiting the application of the procedures described to such particles, i.e., excluding angular particles of crushed stone of the same particle size.

quartzite pebbles (3/4 or 1/2 in.) at 37.8° C (100° F) and 60°C (140° F). The tests were followed by petrographic examination of these bars after this testing was stopped.

7. Nine gravels from the eastern Atlantic Coastal Plain in the United States were received between December 1974 and January 1975 in approximately 50-lb lots. They are identified below:

CL Serial No. CL-1	
G-1	North Carolina, 3 December 1974
G-2	South Carolina, 17 December 1974
G-3	South Carolina, 17 December 1974
G-4	South Carolina, 17 December 1974
G-5	South Carolina, 17 December 1974
G-6	Maryland, 19 December 1974
G-8	Virginia, 24 January 1975
G-9	Virginia, 24 January 1975

A G-7 sample was received but was not used because many of the particles had opal coatings.

8. After initial sieving, a partial petrographic examination was made of each sample. When it was determined that individual quartz and quartzite pebbles were the main constituents of each gravel, specialized testing was done as follows:

- a. Quartz particles were selected from each of the eight gravels to weigh about 500 g. The specific gravity and absorption of each sample was then determined by CRD-C 107 (WES 1949).
- b. Fourteen individual particles were selected, seven from CL-1 G-6 and seven from CL-1 G-8. The specific gravity and absorption of each particle was determined by CRD-C 107. A piece of an

individual quartz crystal was also tested this way to provide reference data. The particles were then cut into halves. One half of each particle was polished and coated with a layer of 80 percent palladium and 20 percent gold. These polished and coated surfaces were next examined by SEM. The coatings were then removed with aqua regia and the cleaned pieces were treated by a version of the quick chemical test (CRD-C 128) (WES 1949) using KOH solution instead of NaOH solution.* The quartz crystal and a piece of chalcedony were also treated with KOH solution. The 14 particle halves were again coated and examined by SEM to evaluate the effects of KOH solution. After final removal of the metal coating, each pebble half was embedded in a vial of 0.4 water-cement ratio high-alkali cement paste (RC-756), sealed, and placed in an oven at about 60° C. The intent was to examine these at a later date for signs of alkali-silica reaction.

c. In the meantime, thin sections were made from each of the other pebble halves. Average undulatory extinction angles were determined by measurement of five to seven different grains in each section. This work was done by K. Mather using the method described by DeHills and Corvalan (1964) and later used by Gogte (1973). K. Mather reported on this work using these 14 sections plus another dozen or so from the same two gravels in 1976.** Several photomicrographs were made.

d. It was observed in the stereomicroscope examination of whole pebbles that typically each pebble had a long dimension and the quartz grains (in quartzite pebbles) had their long dimension subparallel to the long dimension of the pebble. This suggested that the circular sections of the quartz grains would be expected to be subparallel to one another in a plane normal to the long dimension of the pebble. Hence, the pebbles were sawed normal to their long dimension and the thin sections were in the plane of the saw cut. This should have given a concentration of sections of quartz grains normal to the c axis, thus being viewed close to the extinction position. This turned out to be true. There was therefore an opportunity to make comparable observations of extinction angles using quartz grains having similar optical orientation not only within a given pebble but also between pebbles from a gravel and among pebbles from different gravels.

e. Several quartz pebbles were selected from each of the eight gravels. Each of these samples plus a fragment of the quartz crystal used earlier were ground to be between 37 and 45 μm in particle size. These powders were tested in hot sodium carbonate solution and other portions were tested in heated hydrochloric acid to determine their solubility in these solutions. The procedure was that of Schwarz as described in Sosman (1965).

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* KOH was selected since K_2O is the principal alkali present in American portland cements.

** Transportation Research Board Conference Session, 22 January 1976, Washington, DC (unpublished).

f. Portions of some of the same particles used to make thin sections were ground and examined by X-ray diffraction to determine if significant differences in line broadening were recognizable.

g. In addition to the tests described above, individual quartz or quartzite particles were embedded in mortar bars at three different times. These were tested for length change for periods up to 4 years at two temperatures (37.8, 60° C). This was a modification of CRD-C 123 (WES 1949) using pebbles instead of sand sizes and using the higher 60° C temperature in addition to the usual 37.8 (100° F). All of the mortars were made using Ottawa sand to the consistency required by CRD-C 227 (WES 1949). Details of the three groupings are described below:

(1) Five quartz pebbles retained on the 19.0-mm (3/4-in.) sieve were embedded by hand in each of the eight bars made with high-alkali (1.16 percent as Na_2O) cement RC-756. The same was done in eight other bars using the same size quartzite pebbles. The pebbles were from gravels CL-1 G-6 and -8.

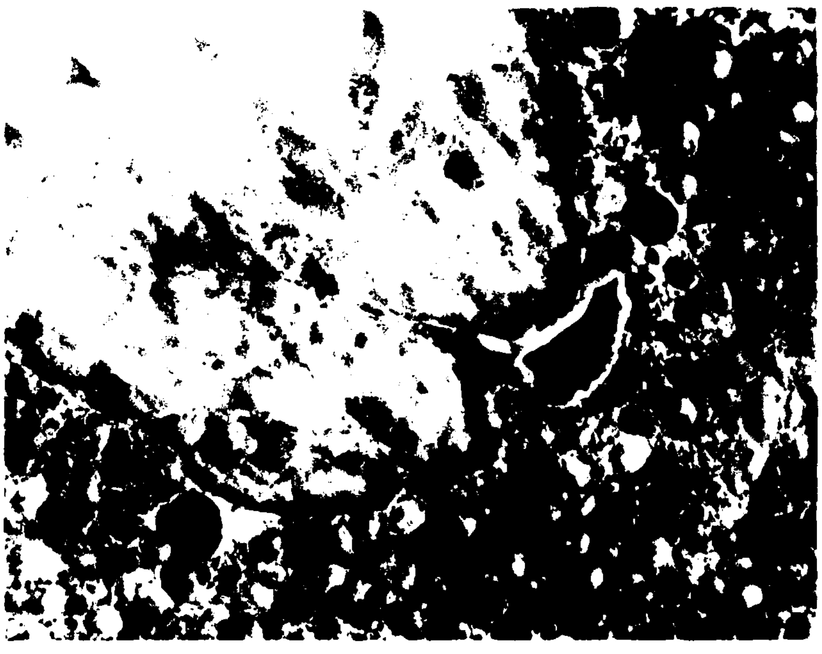
(2) Ten quartz pebbles were embedded in each of two bars for each of the other six gravels. Each pebble was smaller than a 19-mm and retained on a 12.5-mm (1/2-in.) sieve. The same was done with quartzite pebbles. The 24 bars were made with a blend of two high-alkali (1.39 percent as Na_2O) cements (RC-765/766).

(3) There were differences in expansion between the above sets of bars. However, since they differed in pebble size, cement, gravel sample, and number of bars in a container (9 or 6) in addition to number of embedded pebbles, it was not possible to evaluate the latter effect. Therefore, a third group of bars was made using gravels CL-1 G-3 and -8 and cement RC-756. The variable here was five or ten embedded particles per bar for both quartz and quartzite. A total of 48 bars were made.

Results

9. Table 1 shows the grading of the eight natural gravels from the SE Atlantic Coastal Plain. Table 2 shows the predominantly quartz and quartzite composition of most of these gravels and density and absorption data for nominal 500-g samples of quartz from each sample. Density ranged from 2.62 to 2.65 and absorption from 0.26 to 0.67 percent. Table 3 shows a combination of data for individual quartz and quartzite pebbles from two gravels (CL-1 G-6, -8) plus a quartz crystal and a chalcedony pebble; these include densities ranging from 2.51 to 2.68, absorptions from 0 to 2.6 percent, amounts of silica dissolved in KOH solution, and average undulatory extinction angles based on thin sections (Figure 1a). The general similarity of the solution data and

a. Typical view of strained quartz seen with crossed polarizers in thin section of quartz pebble No. 6, gravel G-6, X 40



b. Sawed and ground surface of quartzite pebble, gravel G-1, in mortar bar after several years of length-change testing, X 5. Alkali-silica reaction rim on cracked pebble and alkali-silica gel in void at right center

Figure 1

extinction angles is an indication of the overall similarity of these and the other gravels. The much larger amount of chalcedony dissolved indicates its greater level of reactivity. In addition, examination of these pebble halves by SEM before and after the KOH solution treatment did not reveal significant differences between particles. The general effect of the alkali solution was to enlarge existing features such as cracks or surface vugs or grain contacts (Figure 2). Table 4 shows solubility data in sodium carbonate solution and hydrofluoric acid for powdered quartz pebbles from each gravel and a quartz crystal intended to serve as a control. Once again, there was an overall similarity in results.

10. Tables 5 and 6 show expansion data at two temperatures for the first 16 mortar bars made with embedded quartz or quartzite pebbles from gravels G-6 and G-8 through 4 years of testing. Tables 7 and 8 show similar data through 42 months for quartz and quartzite pebbles in 24 bars from the other 6 gravels. Differences in these bars and the previous set were use of 10 instead of 5 embedded pebbles, use of smaller pebbles, use of different cements, different gravels, and number of bars per container. The expansions were somewhat smaller with 10 pebbles per bar, but it was not apparent if this was the reason for this difference. Tables 9 through 12 show expansion data through 36 months for the final group of 48 bars made with 5 and 10 embedded pebbles of quartz and quartzite from gravels G-3 and G-8. These data were intended to reveal whether the number of embedded pebbles was a significant variable. Study of the expansion data in these eight tables indicated the following:

a. More expansion with five than with ten embedded pebbles.

b. More expansion at 60° C.

c. More expansion with increasing age.

d. Expansion was similar for all eight gravels and similar for quartz and quartzite.

e. Significant expansion, perhaps about 0.07 percent or more, required more than 12 months to develop at either temperature.

f. The higher alkali cements (combination of RC-765 and -766, about 1.4 percent alkali as Na_2O) used for the bars in Tables 7 and 8 did not result in significantly more expansion than the lower alkali RC-756 (about 1.2 percent as Na_2O) cement used for the bars of Tables 5 and 6 and 9 through 12. The significance of this observation was not clear. One possibility is that this lack of difference was because the reactive aggregate in these bars was not at its pessimum level for this cement.

a. Portion of typical surface of polished quartzite pebble No. 7, Sample G-6, before treatment with KOH, X 1000 (No. 010776-21)

b. View of essentially same surface after treatment with KOH, X 1000 (011276-9). Slight effect of KOH treatment is apparent. Upper right shows attack on reference mark

Figure 2

11. Examination of these mortar bars after several years of testing did reveal sufficient evidence in the form of alkali-silica gel, rimmed and cracked quartz and quartzite pebbles to permit the conclusion that alkali-silica reaction had occurred (Figure 1b). Since this was so, no detailed inspection of the 14 pebbles halves that had been placed in high-alkali cement paste in vials and heated was made.

12. In general, it can be said that the characterization tests made on these gravels did not indicate significant differences between them in terms of potential reactivity (Tables 1-4). While not specifically shown, this also includes the XRD work done on line broadening. However, the length-change tests (Tables 5-12) and posttest examinations did prove that alkali-silica reaction had been caused to occur with all of these gravels in the laboratory. Knowing this, it is apparent that the characterization tests should not have showed differences since the gravels were all about equally reactive. Based on all of these results plus those from other work using reactive granite gneiss (Buck, Mather), it was concluded that strained quartz was the reactive constituent in all of these materials. Therefore, the length-change data using embedded particles in mortar bars plus the work of K. Mather on undulatory extinction angles amplified by later work by L. Dolar-Mantuani (1981) were the basis for the development of criteria for recognition of reactive strained quartz before its use as concrete aggregate. Presentation of these data was the basis for an earlier report (Buck 1983), a paper (Buck 1983a), and a revision of Appendix B of EM 1110-2-2000 (HQUSACE 1983) incorporating these new criteria. The criteria for recognition of reactive strained quartz are the presence of more than 20 percent of such quartz in an aggregate and an average undulatory extinction angle greater than 15 degrees. Recognition should be followed by a mortar bar test at 60° C using sand or embedded particles of coarse aggregate; significant expansion is defined as 0.025 percent or more at 6 months and 0.040 percent or more at 12 months (Buck 1983, 1983a). These expansion criteria are for strained quartz only and are not intended to change the usual expansion limits for other materials.

Conclusions

13. Eight quartz and quartzite gravels from the SE Atlantic Coastal Plain were tested in the laboratory and found to cause recognizable alkali-silica

reaction due to the presence of strained quartz in them. Criteria for recognition of reactive strained quartz on the basis of its amount in a sample and its average undulatory extinction angle were developed. These values are more than 20 percent strained quartz in an aggregate with an average undulatory extinction angle of more than 15 degrees. Additional criteria to verify such recognition consist of length-change testing of mortar bars containing strained quartz sand or five embedded pebbles at 60° C; expansion of at least 0.025 percent at 6 months or at least 0.04 percent at 12 months indicates potential deleterious reactivity. These criteria have been incorporated into Appendix B of EM 1110-2-2000 (HQUSACE 1983).

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Table 1

Grading of Eight Natural Gravels

(CL-1 G-1 through-6, -8 and-9)

Sieve Sizes	Individual % Retained, Gravels CL-1 G- 1	2	3	4	5	6	8	9
25.0 mm (1 in.)	--	1.2	4.0	0.5	2.2	--	2.0	--
19.0 mm (3/4 in.)	0.3	21.1	13.1	13.2	19.9	5.7	17.5	15.8
12.5 mm (1/2 in.)	48.5	42.4	46.7	26.2	42.6	38.8	30.8	32.7
9.5 mm (3/8 in.)	25.4	20.4	22.3	30.2	20.3	26.0	16.2	19.1
4.75 mm (No. 4)	23.2	12.5	9.4	24.3	12.8	25.9	24.1	25.0
Passing 4.75 mm	2.6	2.4	4.5	5.6	2.2	3.6	9.4	7.4
Total	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0

Table 2

Composition of 16-mm (3/8-in.) Size and Physical

Properties of Quartz in Eight Gravels

Constituents	Amount in 16-mm Size of CL-1 G- 1	2	3	4	5	6	8	9
Quartz	32	60	29	47	28	16	57	73
Quartzite	68	40	68	52	72	81	15	26
Miscellaneous	--	--	3	1	--	3	28	1
Total	100	100	100	100	100	100	100	100
No. of Pieces Examined	691	584	374	539	377	525	490	440
Data for Approximate 500-g Samples of Quartz Particles								
Density	2.63	2.63	2.62	2.64	2.63	2.62	2.64	2.65
Absorption, %	0.42	0.27	0.67	0.26	0.39	0.60	0.67	0.28

Table 3

Data for 14 Individual Gravel Particles, a Quartz Crystal, and a Piece of Chalcedony

Sample	Rock Type	Types of Data: Density*	Absorption	SiO_2 Dissolved in KOH, millimoles SiO_2 per g of Rock**	Average Undulatory Extinction Angle†
CL-1 G-6, Pebble					
No. 1	Quartzite	2.63	0.5	0.005	58
No. 2	Quartzite	2.66	0.5	0.001	40
No. 4	Quartzite	2.61	0.4	0.004	55
No. 5	Quartz	2.64	1.1	0.010	58
No. 6	Quartz	2.63	0.3	0.006	50
No. 7	Quartzite	2.63	0.0	0.006	47
No. 10	Quartzite	2.65	0.3	0.017	54
	Average	2.64	0.4	0.007	52
CL-1 G-8, Pebble					
No. 44	Quartz	2.66	0.2	0.006	36
No. 45	Quartz	2.64	0.6	0.003	60
No. 50	Quartzite	2.66	0.2	0.005	61
No. 52	Quartz	2.68	1.3	0.025	54
No. 53	Quartz	2.51	2.6	0.015	58
No. 54	Quartz	2.64	0.2	0.007	59
No. 56	Quartz	2.63	0.2	0.012	64
	Average	2.65	0.5	0.010	56
Quartz Crystal		2.66	n.d.††	0.007	n.d.
Chalcedony Pebble		n.d.	n.d.	0.141	n.d.

* Done in general accordance with CRD-C 107.
** Based on modification of CRD-C 128.
† Based on five to seven individual grain measurements for each thin section.
†† Not determined.

Table 4

Solubility* of Quartz in Na_2CO_3 and in

Hydrofluoric (HF) Acid

Composite of Several Quartz Pebbles** from CL-1 G-	Amount Dissolved in Hot Na_2CO_3, %†	Amount Dissolved in Heated 5 Percent HF %††
1	0.5	16.4
2	0.5	19.7
3	0.2	18.3
4	0.2	18.4
5	0.6	18.9
6	0.2	19.0
8	0.1	18.1
9	0.6	17.9
Single Quartz Crystal**	0.3	16.6

* Done in accordance with the method of Schwarz (Sosman 1965).

** Ground to be between 37-μm (No. 400) and 45-μm (No. 325) particle size.

† G-1 was a single determination; all of the others are the average of duplicate determinations.

†† Average of two to three determinations per sample.

Table 5

Length Change of Mortar Bars* With Five Embedded Pebbles of Gravel CL-1 G-6 at Two Temperatures

	Length Changes at Ages Shown Below, %**							
	7 Days	28 Days	90 Days	180 Days	1 Year†	2 Years	3 Years	4 Years
Quartz								
37.8° C (100° F)								
Bar 1	0.007	0.013	0.020	0.025	0.035	0.055	0.068	0.086
Bar 2	0.008	0.012	0.020	0.026	0.034	0.055	0.067	0.086
Average	0.008	0.012	0.020	0.026	0.034	0.055	0.068	0.086
60° C (140° F)								
Bar 3	0.011	0.018	0.023	0.027	0.041	0.057	0.080	0.107
Bar 4	0.011	0.018	0.023	0.027	0.041	0.052	0.077	0.104
Average	0.011	0.018	0.023	0.027	0.041	0.054	0.078	0.106
Quartzite								
37.8° C (100° F)								
Bar 1	0.006	0.013	0.020	0.023	0.032	0.056	0.067	0.086
Bar 2	0.008	0.013	0.020	0.025	0.033	0.054	0.067	0.087
Average	0.007	0.013	0.020	0.024	0.032	0.055	0.067	0.086
60° C (140° F)								
Bar 3	0.013	0.019	0.023	0.027	0.041	0.055	0.077	0.107
Bar 4	0.014	0.020	0.024	0.029	0.040	0.056	0.079	0.088
Average	0.014	0.020	0.024	0.028	0.040	0.056	0.078	0.098

* Made with high-alkali cement RC-756 with 1.16 percent alkali as Na_2O, Ottawa sand, and 19.0-mm to 25.0-mm (3/4-in. to 1-in.) pebbles.

** All values are positive.

† Bars were heated to 82.2° C (180° F) for 1 month by error when they were 9 months old.

Table 6

Length Change of Mortar Bars* With Five Embedded Pebbles of Gravel CL-1 G-8 at Two Temperatures

	Length Changes at Ages Shown Below, %**							
	7 Days	28 Days	90 Days	180 Days	1 Year†	2 Years	3 Years	4 Years
Quartz								
37.8° C (100° F)								
Bar 1	0.008	0.014	0.021	0.027	0.036	0.060	0.070	0.090
Bar 2	0.011	0.014	0.022	0.027	0.036	0.058	0.069	0.090
Average	0.010	0.014	0.022	0.027	0.036	0.059	0.070	0.090
60° C (140° F)								
Bar 3	0.012	0.019	0.023	0.027	0.042	0.055	0.079	0.109
Bar 4	0.013	0.019	0.023	0.026	0.041	0.054	0.077	0.104
Average	0.012	0.019	0.023	0.026	0.042	0.054	0.078	0.106
Quartzite								
37.8° C (100° F)								
Bar 1	0.007	0.013	0.020	0.027	0.036	0.059	0.069	0.090
Bar 2	0.007	0.013	0.019	0.025	0.034	0.057	0.066	0.086
Average	0.007	0.013	0.020	0.026	0.035	0.058	0.068	0.088
60° C (140° F)								
Bar 3	0.013	0.018	0.025	0.029	0.044	0.057	0.080	0.110
Bar 4	0.012	0.020	0.024	0.027	0.040	0.052	0.077	0.109
Average	0.012	0.019	0.024	0.028	0.042	0.054	0.078	0.110

* Made with high-alkali cement RC-756 with 1.16 percent alkali as Na_2O, Ottawa sand, and 19.0-mm to 25.0-mm (3/4- to 1-in.) pebbles.

** All values are positive.

† Bars were heated at 82.2° C (180° F) for 1 month by error when they were 9 months old.

Table 7

Length Change of Mortar Bars* With 10 Embedded Quartz Pebbles† Per Bar at Two Temperatures**

	Length Change at Ages Shown Below, %																		
	Days											Months							
Sample	7	14	28	56	90	118	146	180	236	292	365	15	18	21	23	25	30	36	42
37.8° C (100° F) Storage***																			
CL-1 G-																			
1	0.007	0.009	0.012	0.016	0.018	0.020	0.020	0.023	0.026	0.030	0.037	0.035	0.039	0.045	0.047	0.054	0.059	0.079	0.069
2	0.007	0.009	0.011	0.016	0.017	0.019	0.019	0.022	0.024	0.028	0.034	0.035	0.037	0.043	0.045	0.047	0.057	0.078	0.069
3	0.008	0.009	0.010	0.016	0.018	0.019	0.020	0.023	0.026	0.030	0.036	0.038	0.041	0.045	0.047	0.050	0.059	0.080	0.072
4	0.008	0.009	0.010	0.014	0.016	0.019	0.021	0.023	0.025	0.028	0.036	0.036	0.045	?	0.046	0.046	0.058	0.077	0.069
5	0.006	0.007	0.008	0.013	0.015	0.016	0.016	0.019	0.022	0.026	0.033	0.033	0.034	0.041	0.046	0.046	0.057	0.077	0.067
9	0.005	0.006	0.009	0.013	0.015	0.016	0.017	0.020	0.022	0.026	0.033	0.033	0.035	0.040	0.042	0.047	0.054	0.074	0.065
Range	0.005-0.008	0.006-0.009	0.008-0.012	0.013-0.016	0.015-0.018	0.016-0.02	0.016-0.021	0.019-0.023	0.022-0.026	0.026-0.030	0.033-0.037	0.033-0.038	0.034-0.045	0.040-0.045	0.042-0.047	0.046-0.054	0.054-0.059	0.074-0.080	0.065-0.072

	Length Change at Ages Shown Below, %																		
	Days											Months							
Sample	7	14	28	56	90	118	146††	180	236	292	365	15	18	21	23	25	30	36	42
60° C (140° F) Storage***																			
CL-1 G-																			
1	0.009	0.010	0.014	0.016	0.018	0.017	0.024	--	0.029	0.032	0.039	0.039	0.040	0.053	0.052	0.054	0.065	0.102	0.074
2	0.010	0.011	0.014	0.015	0.016	0.017	0.022	--	0.026	0.031	0.038	0.038	0.044	0.053	0.051	0.054	0.063	0.102	0.074
3	0.010	0.012	0.016	0.018	0.020	0.019	0.024	--	0.028	0.033	0.039	0.040	0.045	0.050	0.053	0.053	0.067	0.105	0.073
4	0.011	0.014	0.016	0.019	0.020	0.021	0.027	--	0.031	0.035	0.043	0.043	0.043	0.056	0.057	0.064	0.070	0.106	0.079
5	0.009	0.011	0.014	0.017	0.018	0.018	0.024	--	0.029	0.033	0.040	0.040	0.040	0.051	0.052	0.057	0.066	0.104	0.074
9	0.010	0.011	0.015	0.017	0.019	0.019	0.025	--	0.031	0.034	0.042	0.042	0.041	0.055	0.055	0.057	0.069	0.106	0.078
Range	0.009-0.011	0.010-0.014	0.014-0.016	0.015-0.019	0.016-0.020	0.017-0.021	0.022-0.027	--	0.026-0.031	0.031-0.035	0.038-0.043	0.038-0.043	0.040-0.045	0.050-0.056	0.051-0.057	0.053-0.064	0.063-0.070	0.102-0.106	0.073-0.079

* Made in accordance with CRD-C 227-78.
** Two high-alkali cements (RC-765 and RC-766) were combined; the alkali content as Na_2O was 1.39 percent.
*** Modified containers with fewer bars (6).
† Each pebble was larger than 12.5 mm (1/2 in.) and smaller than 19.0 mm (3/4 in.).
†† Temperature increased to 180° F for about 1 month by error.

Table 8

Length Change of Mortar Bars* With 10 Embedded Quartzite† Pebbles at Two Temperatures**

	Length Change at Ages Shown Below, %																		
	Days											Months							
Sample	7	14	28	56	90	118	146	180	236	292	365	15	18	21	23	25	30	36	42
37.8° C (100° F) Storage***																			
CL-1 G-																			
1	0.007	0.008	0.011	0.015	0.017	0.018	0.020	0.022	0.025	0.029	0.037	0.037	0.036	0.039	0.045	0.049	0.059	0.079	0.068
2	0.006	0.007	0.010	0.013	0.014	0.015	0.015	0.019	0.022	0.024	0.032	0.034	0.034	0.041	0.044	0.046	0.055	0.076	0.066
3	0.006	0.007	0.010	0.014	0.016	0.017	0.018	0.020	0.024	0.027	0.034	0.036	0.036	0.043	0.048	0.048	0.056	0.078	0.068
4	0.008	0.009	0.012	0.016	0.017	0.018	0.020	0.022	0.025	0.028	0.036	0.036	0.036	0.043	0.048	0.048	0.057	0.078	0.068
5	0.006	0.009	0.014	0.016	0.018	0.016	0.017	0.020	0.022	0.026	0.033	0.033	0.033	0.041	0.043	0.043	0.056	0.077	0.067
9	0.006	0.008	0.010	0.013	0.016	0.017	0.018	0.021	0.023	0.027	0.034	0.036	0.033	0.042	0.048	0.046	0.055	0.077	0.067
Range	0.006- 0.008	0.007- 0.009	0.010- 0.014	0.013- 0.016	0.014- 0.018	0.015- 0.018	0.015- 0.020	0.019- 0.022	0.022- 0.025	0.024- 0.029	0.032- 0.037	0.033- 0.037	0.033- 0.036	0.039- 0.043	0.043- 0.048	0.043- 0.049	0.055- 0.059	0.076- 0.079	0.066- 0.068

	Length Change at Ages Shown Below, %																		
	Days											Months							
Sample	7	14	28	56	90	118	146††	180	236	292	365	15	18	21	23	25	30	36	42
60° C (140° F) Storage***																			
CL-1 G-																			
1	0.010	0.011	0.014	0.017	0.020	0.021	0.024	0.030	0.032	0.037	0.041	0.042	0.046	0.053	0.054	0.057	0.068	0.106	0.078
2	0.014	0.015	0.018	0.022	0.023	0.023	0.027	0.031	0.033	0.035	0.042	0.044	0.045	0.054	0.055	0.055	0.068	0.111	0.081
3	0.015	0.016	0.020	0.023	0.024	0.025	0.027	0.032	0.035	0.038	0.042	0.044	0.046	0.056	0.063	0.060	0.069	0.110	0.083
4	0.012	0.012	0.016	0.018	0.018	0.020	0.025	0.030	0.032	0.037	0.040	0.043	0.047	0.054	0.055	0.060	0.067	0.109	0.079
5	0.009	0.014	0.017	0.019	0.022	0.018	0.022	0.027	0.030	0.034	0.037	0.040	0.046	0.049	0.054	0.054	0.063	0.104	0.075
9	0.011	0.012	0.015	0.017	0.017	0.019	0.024	0.027	0.030	0.035	0.038	0.040	0.043	0.051	0.054	0.056	0.066	0.106	0.079
Range	0.009- 0.015	0.011- 0.016	0.014- 0.020	0.017- 0.023	0.017- 0.024	0.018- 0.025	0.022- 0.027	0.027- 0.032	0.030- 0.035	0.034- 0.038	0.037- 0.042	0.040- 0.044	0.043- 0.047	0.049- 0.056	0.054- 0.063	0.054- 0.060	0.063- 0.069	0.104- 0.111	0.075- 0.083

* Made in accordance with CRD-C 227-78.

** Two high-alkali cements (RC-765 and RC-766) were combined; the alkali content as Na_2O was 1.39 percent.

*** Modified containers with fewer bars (6).

† Each pebble was larger than 12.5 mm (1/2 in.) and smaller than 19.0 mm (3/4 in.).

†† Temperature increased to 180° F for about 1 month by error.

Table 9

Length Change of Mortar Bars* Made With Five or Ten Embedded Pebbles† of Quartz and Portland Cement RC-756** at Two Temperatures

		Length Change at Ages Shown Below, %																
		Days									Months							
Sample CL-1 G-3	Bar No.††	14	28	56	90	118	146	180	270	365	15	18	21	24	27	30	33	36
With 5 pebbles	1	0.012	0.015	0.021	0.025	0.026	0.030	0.032	0.037	0.037	0.045	0.048	0.048	0.057	0.064	0.069	0.070	0.071
Stored at	2	0.012	0.015	0.020	0.025	0.025	0.029	0.031	0.035	0.034	0.044	0.046	0.048	0.057	0.063	0.066	0.070	0.070
37.8° C (100° F)	3	0.011	0.015	0.020	0.023	0.024	0.027	0.029	0.035	0.032	0.043	0.044	0.046	0.056	0.060	0.065	0.065	0.066
	Average	0.012	0.015	0.020	0.024	0.025	0.028	0.031	0.036	0.034	0.044	0.046	0.047	0.057	0.062	0.067	0.068	0.069
With 5 pebbles	4	0.015	0.018	0.023	0.027	0.028	0.031	0.033	0.038	0.039	0.046	0.046	0.054	0.061	0.068	0.081	0.074	0.074
Stored at	5	0.016	0.020	0.024	0.028	0.029	0.032	0.034	0.039	0.040	0.048	0.049	0.059	0.060	0.069	0.080	0.076	0.076
60° C (140° F)	6	0.015	0.019	0.023	0.026	0.027	0.031	0.032	0.037	0.037	0.046	0.048	0.056	0.058	0.067	0.079	0.073	0.073
	Average	0.015	0.019	0.023	0.027	0.028	0.031	0.033	0.037	0.039	0.046	0.048	0.056	0.060	0.068	0.080	0.074	0.074

		Length Change at Ages Shown Below, %																
		Days									Months							
Sample CL-1 G-3	Bar No.††	14	28	56	90	118	146	180	270	365	15	18	21	24	27	30	33	36
With 10 pebbles	7	0.010	0.013	0.017	0.022	0.022	0.026	0.029	0.036	0.036	0.047	0.047	0.051	0.059	0.065	0.069	0.072	0.072
Stored at	8	0.009	0.013	0.017	0.021	0.021	0.025	0.028	0.031	0.030	0.039	0.038	0.042	0.053	0.057	0.064	0.062	0.062
37.8° C (100° F)	9	0.009	0.013	0.018	0.022	0.022	0.026	0.029	0.033	0.032	0.041	0.042	0.044	0.054	0.058	0.065	0.064	0.065
	Average	0.009	0.013	0.017	0.022	0.022	0.026	0.029	0.033	0.033	0.042	0.042	0.046	0.055	0.060	0.066	0.066	0.066
With 10 pebbles	10	0.015	0.018	0.022	0.026	0.028	0.031	0.034	0.039	0.038	0.047	0.046	0.057	0.060	0.069	0.081	0.071	0.074
Stored at	11	0.015	0.018	0.022	0.026	0.027	0.030	0.032	0.037	0.037	0.046	0.045	0.054	0.058	0.066	0.077	0.071	0.071
60° C (140° F)	12	0.014	0.018	0.023	0.026	0.028	0.030	0.032	0.040	0.038	0.047	0.045	0.057	0.058	0.069	0.080	0.073	0.074
	Average	0.015	0.018	0.022	0.026	0.028	0.030	0.033	0.038	0.038	0.041	0.045	0.056	0.059	0.068	0.079	0.072	0.073

* Made in accordance with CRD-C 227-78.

** 1.16 percent alkali as Na_2O.

† Each pebble was larger than 12.5 mm (1/2 in.) and smaller than 19.0 mm (3/4 in.).

†† Modified containers with fewer bars (6).

Table 10

Length Change of Mortar Bars* Made With Five or Ten Embedded Pebbles† of Quartzite and Portland Cement RC-756** at Two Temperatures

		Length Change at Ages Shown Below, %																
		Days									Months							
Sample CL-1 G-3	Bar No.††	14	28	56	90	118	146	180	270	365	15	18	21	24	27	30	33	36
With 5 pebbles	13	0.012	0.015	0.020	0.025	0.025	0.029	0.031	0.033	0.034	0.042	0.042	0.047	0.054	0.060	0.066	0.066	0.066
Stored at	14	0.012	0.016	0.021	0.026	0.025	0.029	0.032	0.036	0.036	0.044	0.045	0.049	0.058	0.064	0.067	0.071	0.071
37.8° C (100° F)	15	0.012	0.016	0.021	0.026	0.025	0.029	0.032	0.036	0.037	0.045	0.045	0.049	0.058	0.065	0.067	0.067	0.067
	Average	0.012	0.016	0.021	0.026	0.025	0.029	0.032	0.035	0.036	0.044	0.044	0.048	0.057	0.063	0.067	0.068	0.068
With 5 pebbles	16	0.018	0.021	0.024	0.028	0.030	0.032	0.034	0.041	0.041	0.050	0.049	0.061	0.062	0.071	0.081	0.076	0.079
Stored at	17	0.018	0.021	0.024	0.028	0.030	0.031	0.034	0.040	0.040	0.047	0.047	0.059	0.06.	0.071	0.080	0.075	0.078
60° C (140° F)	18	0.018	0.021	0.023	0.028	0.030	0.032	0.035	0.040	0.040	0.048	0.050	0.061	0.063	Broke------	------	------	------
	Average	0.018	0.021	0.024	0.028	0.030	0.032	0.034	0.040	0.040	0.048	0.049	0.060	0.063	0.071	0.080	0.076	0.078

		Length Change at Ages Shown Below, %																
		Days									Months							
Sample CL-1 G-3	Bar No.††	14	28	56	90	118	146	180	270	365	15	18	21	24	27	30	33	36
With 10 pebbles	19	0.011	0.015	0.019	0.023	0.023	0.027	0.029	0.033	0.034	0.042	0.042	0.047	0.054	0.062	0.065	0.064	0.065
Stored at	20	0.010	0.014	0.019	0.023	0.022	0.026	0.029	0.033	0.034	0.042	0.042	0.043	0.054	0.063	0.064	0.066	0.066
37.8° C (100° F)	21	0.013	0.015	0.020	0.024	0.023	0.027	0.030	0.033	0.034	0.041	0.041	0.046	0.055	0.061	0.066	0.068	0.068
	Average	0.011	0.015	0.019	0.023	0.023	0.027	0.029	0.033	0.034	0.042	0.042	0.045	0.054	0.062	0.065	0.066	0.066
With 10 pebbles	22	0.016	0.018	0.022	0.027	0.030	0.032	0.034	0.040	0.042	0.049	0.049	0.059	0.061	0.071	0.082	0.079	0.079
Stored at	23	0.015	0.019	0.022	0.027	0.029	0.033	0.036	0.043	0.044	0.051	0.051	0.051	0.067	0.075	0.085	0.082	0.082
60° C (140° F)	24	0.017	0.020	0.022	0.026	0.028	0.031	0.033	0.038	0.040	0.047	0.047	0.056	0.060	0.070	0.081	0.075	0.079
	Average	0.016	0.019	0.022	0.027	0.029	0.032	0.034	0.041	0.042	0.049	0.049	0.055	0.063	0.072	0.083	0.079	0.080

* Made in accordance with CRD-C 227-78.

** 1.16 percent alkali as Na_2O.

† Each pebble was larger than 12.5 mm (1/2 in.) and smaller than 19.0 mm (3/4 in.).

†† Modified containers with fewer bars (6).

Table 11

Length Change of Mortar Bars* Made With Five or Ten Embedded Pebbles† of Quartz and Portland Cement RC-756** at Two Temperatures

		Length Change at Ages Shown Below, %																
		Days									Months							
Sample CL-1 G-8	Bar No.††	14	28	56	90	118	146	180	270	365	15	18	21	24	27	30	33	36
With 5 pebbles	25	0.009	0.013	0.017	0.022	0.021	0.025	0.028	0.033	0.033	0.041	0.041	0.048	0.052	0.059	0.063	0.065	0.065
Stored at	26	0.012	0.016	0.019	0.024	0.024	0.028	0.031	0.035	0.034	0.043	0.043	0.049	0.058	0.062	0.066	0.066	0.068
37.8° C (100° F)	27	0.010	0.014	0.018	0.023	0.023	0.027	0.029	0.034	0.034	0.041	0.041	0.047	0.054	0.060	0.064	0.065	0.066
	Average	0.010	0.014	0.018	0.023	0.023	0.027	0.029	0.034	0.034	0.041	0.041	0.048	0.055	0.060	0.064	0.065	0.066
With 5 pebbles	28	0.014	0.017	0.022	0.026	0.028	0.029	0.031	0.038	0.038	0.045	0.046	0.056	0.060	0.069	0.081	0.074	0.076
Stored at	29	0.013	0.016	0.020	0.025	0.026	0.026	0.031	0.037	0.036	0.041	0.043	0.055	0.060	0.066	0.077	0.073	0.075
60° C (140° F)	30	0.013	0.018	0.021	0.025	0.028	0.028	0.031	0.031	0.038	0.046	0.047	0.057	0.058	0.069	0.079	0.074	0.078
	Average	0.013	0.017	0.021	0.025	0.027	0.027	0.031	0.035	0.037	0.044	0.045	0.056	0.059	0.068	0.079	0.074	0.076

		Length Change at Ages Shown Below, %																
		Days									Months							
Sample CL-1 G-8	Bar No.††	14	28	56	90	118	146	180	270	365	15	18	21	24	27	30	33	36
With 10 pebbles	31	0.010	0.013	0.018	0.022	0.022	0.025	0.028	0.031	0.030	0.040	0.040	0.046	0.052	0.058	0.063	0.064	0.064
Stored at	32	0.010	0.013	0.018	0.022	0.022	0.027	0.029	0.033	0.031	0.044	0.044	0.049	0.055	0.059	0.064	0.069	0.069
37.8° C (100° F)	33	0.009	0.012	0.016	0.020	0.020	0.025	0.027	0.031	0.028	0.038	0.038	0.045	0.051	0.057	0.061	0.060	0.063
	Average	0.010	0.013	0.017	0.021	0.021	0.026	0.028	0.032	0.030	0.041	0.041	0.047	0.053	0.058	0.063	0.064	0.065
With 10 pebbles	34	0.014	0.017	0.021	0.025	0.027	0.028	0.031	0.035	0.037	0.042	0.042	0.054	0.059	0.067	0.078	0.069	0.072
Stored at	35	0.013	0.016	0.020	0.024	0.027	0.028	0.032	0.036	0.037	0.045	0.044	0.057	0.058	0.068	0.080	0.075	0.076
60° C (140° F)	36	0.013	0.015	0.018	0.024	0.024	0.024	0.027	0.032	0.032	0.041	0.040	0.051	0.053	0.063	0.071	0.066	0.071
	Average	0.013	0.016	0.020	0.024	0.026	0.027	0.036	0.034	0.035	0.043	0.042	0.054	0.057	0.066	0.076	0.070	0.073

* Made in accordance with CRD-C 227-78.

** 1.16 percent alkali as Na_2O.

† Each pebble was larger than 12.5 mm (1/2 in.) and smaller than 19.0 mm (3.4 in.).

†† Modified containers with fewer bars (6).

Table 12

Length Change of Mortar Bars* Made With Five and Ten Embedded Pebbles† of Quartzite and Portland Cement RC-756** at Two Temperatures

		Length Change at Ages Shown Below, %																
		Days									Months							
Sample CL-1 G-8	Bar No.††	14	28	56	90	118	146	180	270	365	15	18	21	24	27	30	33	36
With 5 pebbles	37	0.010	0.014	0.017	0.022	0.021	0.025	0.028	0.032	0.031	0.041	0.042	0.043	0.050	0.058	0.065	0.064	0.064
Stored at	38	0.011	0.015	0.018	0.024	0.023	0.027	0.030	0.035	0.033	0.042	0.042	0.046	0.055	0.059	0.064	0.066	0.066
37.8° C (100° F)	39	0.010	0.014	0.017	0.022	0.022	0.026	0.029	0.034	0.032	0.042	0.042	0.047	0.057	0.060	0.064	0.066	0.068
	Average	0.010	0.014	0.017	0.023	0.022	0.026	0.029	0.034	0.032	0.042	0.042	0.045	0.054	0.059	0.064	0.065	0.066
With 5 pebbles	40	0.018	0.020	0.025	0.031	0.032	0.033	0.036	0.041	0.041	0.051	0.053	0.063	0.060	0.071	0.081	0.075	0.079
Stored at	41	0.015	0.017	0.023	0.028	0.030	0.031	0.033	0.041	0.039	0.049	0.050	0.053	0.060	0.070	0.072	0.073	0.078
60° C (140° F)	42	0.016	0.018	0.022	0.026	0.029	0.030	0.033	0.040	0.040	0.050	0.050	0.067	0.060	0.070	0.071	0.074	0.077
	Average	0.016	0.018	0.023	0.028	0.030	0.031	0.034	0.041	0.040	0.050	0.051	0.064	0.060	0.070	0.075	0.074	0.078

		Length Change at Ages Shown Below, %																
		Days									Months							
Sample CL-1 G-8	Bar No.††	14	28	56	90	118	146	180	270	365	15	18	21	24	27	30	33	36
With 10 pebbles	43	0.011	0.014	0.018	0.022	0.020	0.025	0.027	0.032	0.031	0.039	0.039	0.047	0.052	0.058	0.063	0.063	0.063
Stored at	44	0.010	0.013	0.018	0.022	0.021	0.025	0.028	0.032	0.032	0.039	0.040	0.045	0.055	0.058	0.062	0.062	0.065
37.8° C (100° F)	45	0.009	0.012	0.015	0.021	0.020	0.025	0.027	0.031	0.029	0.038	0.039	0.043	0.049	0.056	0.064	0.061	0.064
	Average	0.010	0.013	0.017	0.022	0.020	0.025	0.027	0.032	0.031	0.039	0.039	0.045	0.052	0.057	0.063	0.062	0.064
With 10 pebbles	46	0.014	0.016	0.020	0.023	0.026	0.027	0.029	0.035	0.038	0.044	0.045	0.055	0.055	0.065	0.075	0.069	0.071
Stored at	47	0.014	0.016	0.021	0.025	0.027	0.028	0.031	0.037	0.036	0.046	0.046	0.054	0.057	0.067	0.068	0.070	0.075
60° C (140° F)	48***																	
	Average	0.014	0.016	0.020	0.024	0.026	0.028	0.030	0.036	0.037	0.045	0.046	0.054	0.056	0.066	0.072	0.070	0.073

* Made in accordance with CRD-C 227-78.

** 1.16 percent alkali as Na_2O.

† Each pebble was larger than 12.5 mm (1/2 in.) and smaller than 19.0 mm (3/4 in.)

†† Modified containers with fewer bars (6).

*** Bar 48 data consistently low and not used.

END

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